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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H01S 3/06 — A1

(11) International Publication Number: WO 95/10868

(43) International Publication Date: 20 April 1995 (20.04.95)

(21) International Application Number: PCT/IT93/00107

(22) International Filing Date: 13 October 1993 (13.10.93)

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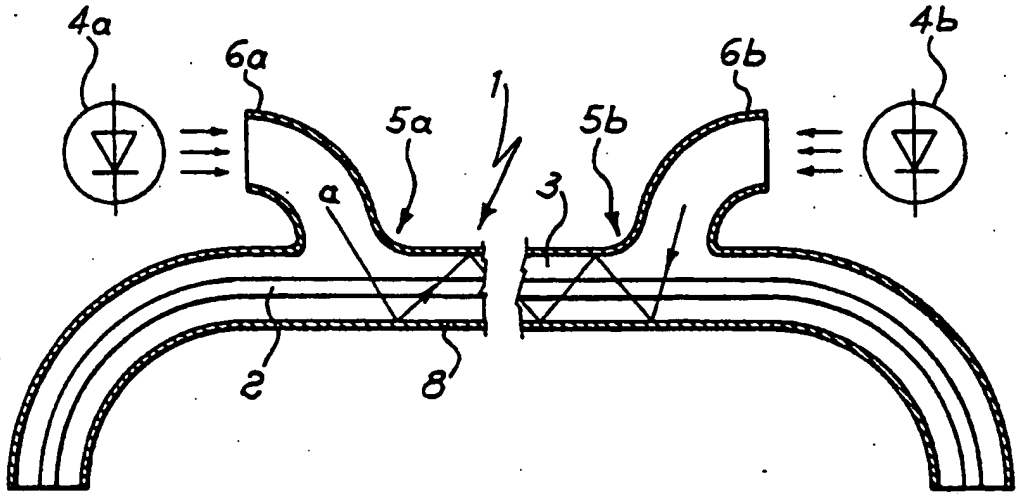
(81) Designated States: AU, CA, JP, RU, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: A HIGH POWER OPTICAL FIBER AMPLIFIER PUMPED BY A MULTI-MODE LASER SOURCE



(57) Abstract

A fiber optic amplifier is made by a fiber (1) with two concentrical cores (2 and 3), the innermost one (2) constituted by amplifying material, the other one (3) used for pumping. Pump radiation is provided by multi-mode sources (4) and coupled, transversally with respect to the optical axis of said fiber (1), to the outer core (3) through multi-mode fibres (6) and multi-mode optical couplers (5). Pump radiation propagates through the outer core (3) and couples to the amplifying core (2), thus pumping the active material. The composition of the amplifying material is chosen in such a way that pumping can take place in a broad range of wavelengths. Coherent or incoherent pump sources can be used.

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"A HIGH POWER OPTICAL FIBER AMPLIFIER PUMPED BY A MULTI-MODE LASER SOURCE"

Technical Field

The invention relates to an improved high power optical fiber amplifier pumped by a multi-mode laser source.

A fiber optic amplifier for telecommunications is constituted by a single-mode optical fiber which core is doped with rare earths like Erbium. Pump power coupled into the fiber provides gain in the active medium for the information signal propagating along the fiber.

Background Art

Currently 980 nm and 1480 nm single-mode laser diodes are used as pump sources for fiber optic amplifiers that are directly coupled to a single-mode fiber and, through a single-mode multiplexer, to the active fiber.

The use of single-mode fibers and the narrow range allowed for the source wavelength require sophisticated packaging techniques, narrow wavelength selection and an accurate thermal stabilization, achieved currently by power consuming Peltier coolers.

Important characteristics of the fiber optic amplifiers such as the gain and saturation power thereof depend on pump intensity. Presently laser diodes with single-mode pigtail are available, at wavelengths suitable for pumping Erbium, with coupled power less than 100 mW, and pump radiation is coupled directly to the end-face of the fiber and particularly into the core of the amplifying fiber through single-mode couplers. This has limited the maximum output power achievable from a single amplifier to about 17 dBm (50 mW) and the maximum gain to about 35 dB.

Pumping directly into the core of the active fiber causes the pump radiation to propagate together with the

optical signal to be amplified, therefore a filter may be required at the output of the amplifier to eliminate residual pump radiation from the transmission line. Counter-propagating pumping schemes have been developed to avoid this problem, by making the pump radiation propagating backwards with respect to the signal, but such configurations increase the noise generated by spontaneous emission, thus degrading the noise figure of the amplifier.

Single-mode pumping, moreover, creates a non flat gain profile across the active medium thus requiring for example the realization of very small core and high numerical aperture active fiber to avoid signal absorption on the tails of the pump beam profile.

In summary the realization of high output power, high gain, low noise, low cost fiber optic amplifiers is limited by the availability and the cost of suitable pump sources which have to be coupled into single-mode fibers and by the pumping method which causes the coexistence of pump and signal radiation propagating along the amplifying core.

Moreover single-mode pumping through single-mode couplers may result in polarization dependence and other losses due to the change in shape of the fiber cores inside the couplers.

US-A- 4 829 529 to Kafka discloses a double core fiber structure for pumping the inner single-mode core doped with a rare earth like Neodymium or Erbium in order to obtain lasing action. This patent shows a double core laser structure, but does not provide for any simultaneous doping with different rare earths, nor suggests that the arrangement could be suitable for producing a fiber optic amplifier and further the coupling of the pump radiation to the fiber is performed through its end faces, using bulk optics.

A work of Minelly et. al. reports amplification by a double core Ytterbium-Erbium doped fiber, but again the pumping is made through the end faces by bulk optics.

Moreover in both works the pump sources are preferably diode arrays.

AU-A-10374/92 discloses an optical fiber amplifier comprising an Erbium doped fiber length, a single-mode coupler for coupling to a pump light source, and a length of Yb doped fiber spliced to the output end of the amplifying fiber for absorbing the residual pump light.

DE-OS 4 005 867 discloses an optical fiber amplifier comprising a Lanthanid doped length of fiber each end of which is coupled to a pump light source to achieve a high amplification of the incoming signal.

EP-A-0 509 577 discloses a two stage optical amplifier with the downstream amplifier comprising a length of active fiber doped with a fluorescent dopant, a coupler for supplying a pump light from a laser diode and a pair of optical insulators.

The present invention aims to overcome the above mentioned limitations and drawbacks.

Objects of the Invention

A first object of the present invention is to provide a fiber optic amplifier with high gain and high output power.

A second object of the present invention is to provide a fiber optic amplifier that effectively suppresses the pumping light outside the lenght of amplifying fiber.

A third object of the present invention is to provide a fiber optic amplifier with an uniform gain profile across the amplifying core of the active fiber.

A further object of the present invention is to provide a fiber optic amplifier capable to make possible the use of pump sources emitting in a broad wavelength range and not requiring accurate thermal stabilization.

Disclosure of Invention

Accordingly these and other objects are realized in the present invention concerning an optical fiber amplifier comprising:

- a lenght of double-clad fiber with:
  - i. a co-doped single-mode core of amplifying material;
  - ii. a multi-mode core surrounding the single-mode core and acting as guide for pump radiation;
  - iii. an outer cladding;
- a pump source coupled to said lenght of double clad fiber,

characterized in that:

- said inner core is of an Erbium-Ytterbium doped material;
- said pump power source comprises at least a multi-mode diode source supplying multi-mode pumping radiation to said lenght of double-clad fiber, transversally with respect to the optical axis of the fiber.

According to the invention:

- the first object is attained by means of said multi-mode diode source with associated multi-mode/high power pumping radiation;
- the second and third object are attained by means of said transverse pumping and consequent transverse path of the pumping radiation with respect to the axial path of the information signal propagating along said lenght of optical fiber: thanks to said transverse path, the pumping radiation does not superimpose the information signal and no absorbing means are needed;
- the fourth object is attained by means of said inner core of an Erbium-Ytterbium doped materials thanks to the broad absorption spectrum of said materials.

Additional characteristics of the present invention will be better understood from the depending claims and in particular the use of multi-mode couplers for high efficient coupling of pump multi-mode radiation into the

active fiber in order to perform said transverse pumping. In addition, in order to increase the pump power, at least two multi-mode couplers and two multi-mode diode sources are provided.

Further features and advantages of an optical amplifier according to the invention will become more clearly apparent from the following detailed description of a preferred embodiment of the device illustrated - only as non limiting examples - in the attached drawings, in which:

Brief Description of the Drawings

Fig. 1 is a schematic view of a fiber amplifier according to the invention; and

Fig. 2 is a cross-sectional side view schematically illustrating the active fiber and the coupler to the pumping source.

With reference to the Figures, the amplifier according to the invention comprises a length of optical fiber 1 made by a double concentrical core 2 and 3. With reference in particular to Fig. 1 it is assumed that an optical signal carrying information is propagating along the fiber in the direction shown by arrow S.

The inner core 2 is a single-mode core, with size analogous to those of the standard telecommunications fibers, and is doped with both Ytterbium and Erbium i.e. is Yb/Er co-doped. Thus the active material of the inner core 2 exhibits a broad absorption spectrum and is suitable for providing gain at optical communications wavelengths.

More particularly the codoping with Ytterbium and Erbium of the active core allows for a broad pump wavelength range, between 900 nm and 1000 nm, so that within this range pump sources do not require wavelength selection and accurate temperature stabilization.

The sorrounding core 3 is a multi-mode core used for pumping by coupling pump radiation from a laser diode 4a

through a multi-mode fiber 6a and a multi-mode coupler 5a. An outer cladding 8 surrounds the multi-mode core 3.

The pump light from the pump source is injected transversally with respect to the optical axis of said fiber length 1 through the multi-mode couplers - that, according to a preferred embodiment of the invention are non-symmetrical type - and through multiple reflections (as schematically shown for a beam a in Fig. 2), penetrates into the inner core 2 and is absorbed therein without to superimpose to the optical signal to be amplified.

The multi-mode coupler can be formed, as an example, by a length of multi-mode fiber and a length of double core fiber. According to a preferred embodiment of the invention the multi-mode coupler is formed directly on the active fiber twisting, heating an subsequently pulling the two fibers.

In the diagram of Fig. 1 an additional laser diode 4b is connected to the active fiber 1 through a multi-mode fiber 6b and a second multi-mode coupler 5b for increasing the pump power and in order to achieve a more uniform power distribution along the amplifying fiber which in turn results in improved amplifying characteristics.

Isolators INS1 and INS2 can be further provided along the fiber 1.

Thanks to the fact that the pump radiation does not couple into the amplifying core 2 along the signal direction, no output filter is needed. The gain profile is uniform across the active core, which thus can be made similar in dimensions to standard single-mode telecommunications fibers. The outer cladding provides optical confinement for pump radiation. The use of multi-mode fibers allows for much higher pump powers and the double core pumping scheme together with said transverse pumping makes possible placing several sources along a single active fiber; therefore high gain and output power are achievable.

According to a preferred embodiment the (each) pump source is a multi-mode laser diode and the pumping radiation is a coherent radiation. Alternatively the pumping radiation can be an incoherent radiation, such as that generated, e.g. by a superfluorescent diode.

The single-mode amplifying fiber 1 is preferably made by Erbium-Ytterbium doped glass.

As for what concerns the preferred values,the diameters of the multi-mode pump core and the single-mode amplifying core are in a ratio of about 10:1 and the length of the optical fiber 1 is between 2 and 20m.

Best Mode for Carrying Out the Invention

The best mode for carrying out the invention is the one shown in fig. 2 and comprising two multi-mode fiber optic couplers 6a and 6b in order to obtain high output power and, thanks to the transverse pumping the pump radiation is not superimposed to the optical signal to be amplified, and consequently no filter is required at the output of the amplifier to eliminate residual pump radiation.

Industrial Applicability

The high power optical fiber amplifier is applicable in telecommunication transmission systems and in particular in long haul transmission lines and in distribution networks.

It will be understood by those skilled in the art that various modifications and changes may be made to the present invention without departing from the scope and spirit thereof.

CLAIMS

1. An optical fiber amplifier comprising:

- a lenght of double-clad fiber with:
  - i. a co-doped single-mode core of amplifying material;
  - ii. a multi-mode core surrounding the single-mode core and acting as guide for pump radiation;
  - iii. an outer cladding;
- a pump source coupled to said lenght of double clad fiber,

characterized in that:

- said inner core (2) is of an Erbium-Ytterbium doped material;
- said pump power source (4) comprises at least a multi-mode diode source supplying multi-mode pumping radiation to said lenght of double-clad fiber (1), transversally with respect to the optical axis of the fiber (1).

2. An optical fiber amplifier as claimed in claim 1, characterized in that said transverse pumping is performed by means of at least a multi-mode fiber optic coupler (5) associated to said lenght of double-clad fiber (1).

3. An optical fiber amplifier as claimed in claims 1 and 2, characterized in that said multi-mode coupler (5) is formed directly on the double-clad fiber (1).

4. An optical fiber amplifier as claimed in claims 1 and 2, characterized in that includes two multi-mode diode sources (4a, 4b) and two multi-mode fiber optic couplers (5a, 5b).

5. An optical fiber amplifier as claimed in claims 1 to 4, characterized in that said pumping radiation is a coherent radiation.

6. An optical fiber amplifier as claimed in claims 1 to 4, characterized in that said pumping radiation is an incoherent radiation.

7. An optical fiber amplifier as claimed in claims 1 to 6, characterized in that said pump source is a superluminescent diode.

8. An optical fiber amplifier as claimed in claim 1, characterized in that the single-mode amplifying fiber is made by Erbium-Ytterbium doped glass.

9. An optical fiber amplifier as claimed in the preceding claims, characterized in that the diameters of the multi-mode pump core and the single-mode amplifying core are in a ratio of about 10:1.

10. An optical fiber amplifier as claimed in the preceding claims, characterized in that the length of the optical fiber is between 2 and 20 m.

11. An optical fiber amplifier as claimed in claim 2, characterized in that said multi-mode optic coupler (5) is non-symmetrical type.

Fig.1

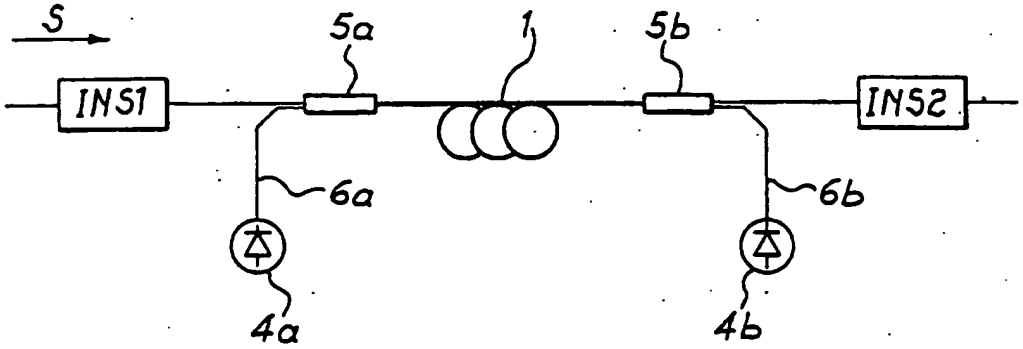
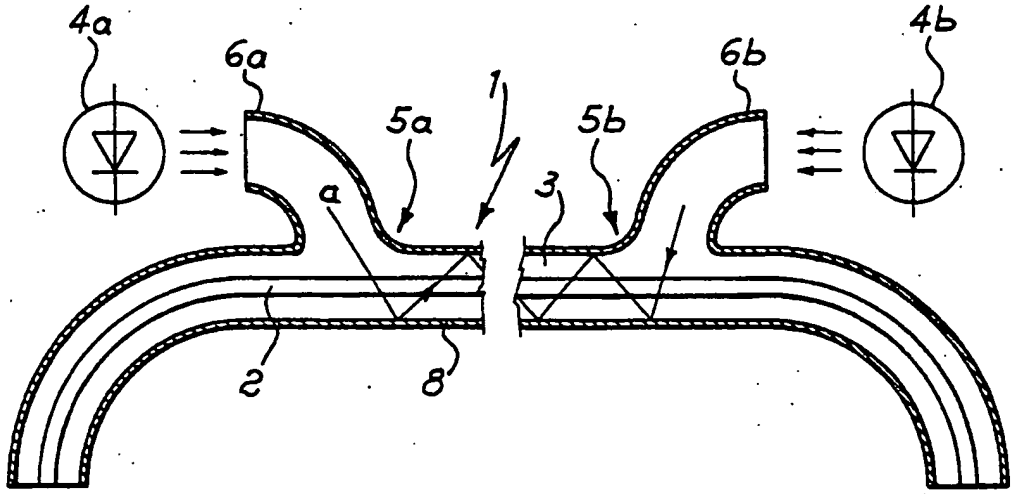


Fig.2



INTERNATIONAL SEARCH REPORT

Inten al Applicabon No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01S3/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP,A,0 320 990 (POLAROID CO) 21 June 1989 see abstract; claims 1,3,4,11,12,23-26; figures 3,5 see column 4, line 30 - line 46	1-11
Y	US,A,5 170 458 (T.AOYAGI ET AL.) 8 December 1992 see column 5, line 36 - line 65	1-11
Y	IEEE PHOTONICS TECHNOLOGY LETTERS, vol.5, no.3, March 1993, NEW YORK US pages 301 - 303, XP000362931 J.D.MINELLY ET AL. 'Diode-array pumping of Er3+/Yb3+ co-doped fiber lasers and amplifiers' see abstract	1-11

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20 June 1994	29.06.94

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 112 090 (THE BOARD OF TRUSTEES OF THE LELAND STANFORD JUNIOR UNIVERSITY) 27 June 1984 see figure 1	1,4

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..formation on patent family members

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Patent document cited in search report	Publication date	Patent family member(s)		Publication date
EP-A-0320990	21-06-89	US-A-	4815079	21-03-89
		DE-A-	3874701	22-10-92
		JP-A-	1260405	17-10-89
US-A-5170458	08-12-92	JP-A-	4192481	10-07-92
EP-A-0112090	27-06-84	US-A-	4546476	08-10-85
		AU-B-	568827	14-01-88
		AU-A-	2161983	14-06-84
		CA-A-	1210483	26-08-86
		DE-A-	3382608	17-09-92
		JP-C-	1777890	28-07-93
		JP-B-	4064197	14-10-92
		JP-A-	59114883	03-07-84